Yb:YAG MOPA System and Non-linear Frequency Conversion Module for Remote Wind Sensing and DIAL based Atmospheric Ozone Concentration Measurements

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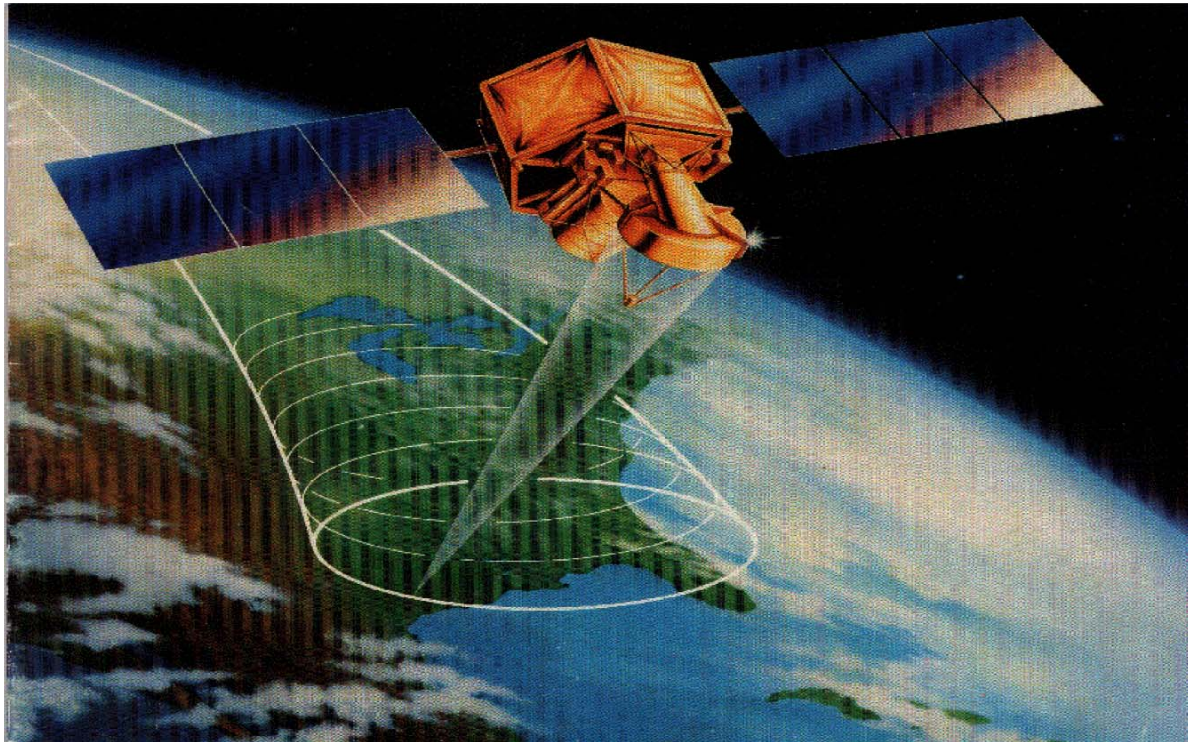
Global wind velocity sensing

- **Measurement specifications**
  - 100 km hor. res., 1 km ver. res. , 1 m/s velocity accuracy, eye safety.

Laser transmitter specifications for wind sensor

- Energy: 2J/pulse
- Repetition rate: 10 Hz
- Pulse width: ~ 1μs
- Linewidth : 1 MHz
- Satellite altitude :400 km
- $\lambda > 1.4\ \mu m$



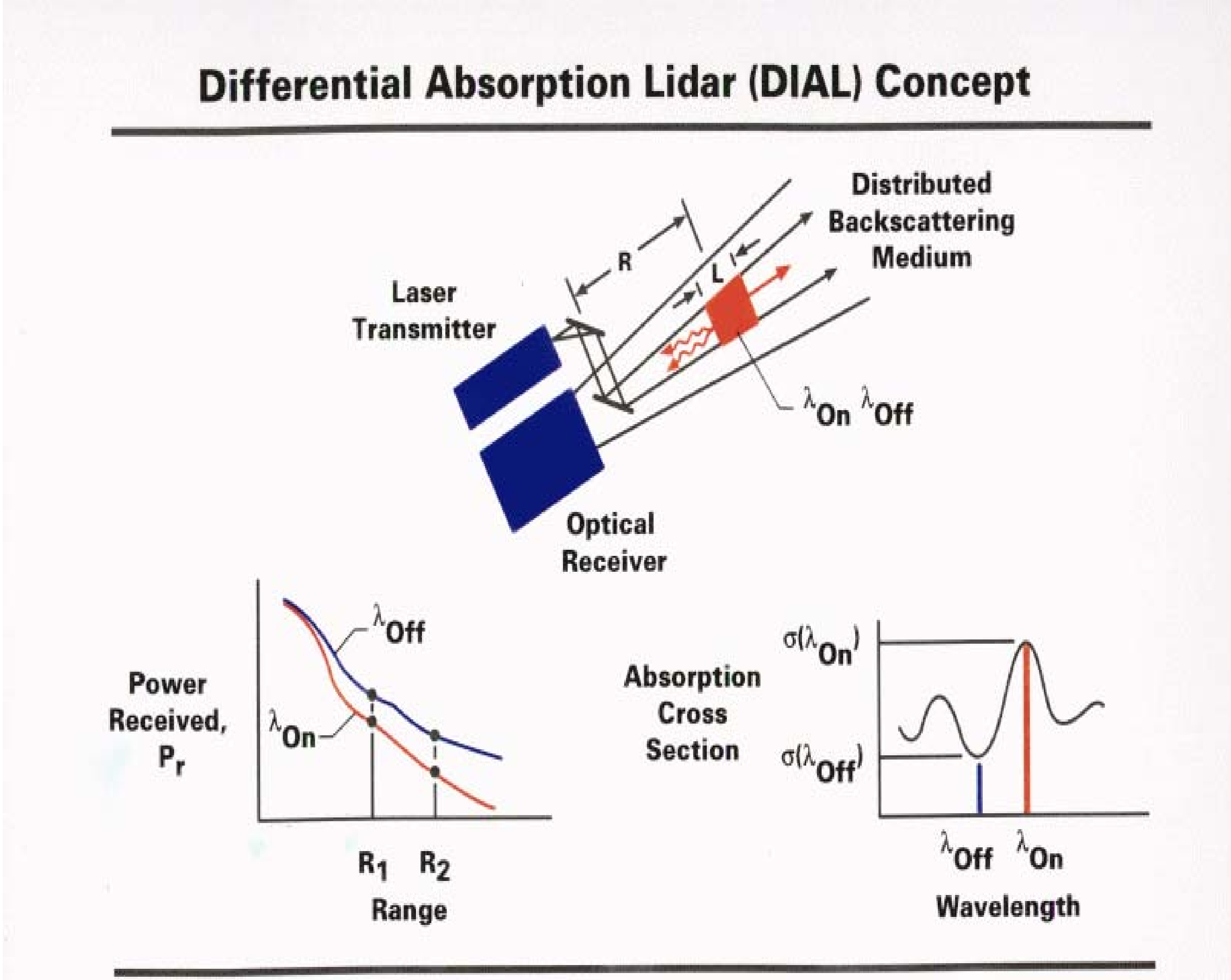
•Currently 2 μm sources developed by NASA/Langley are most advanced in development

DIAL based ozone detection

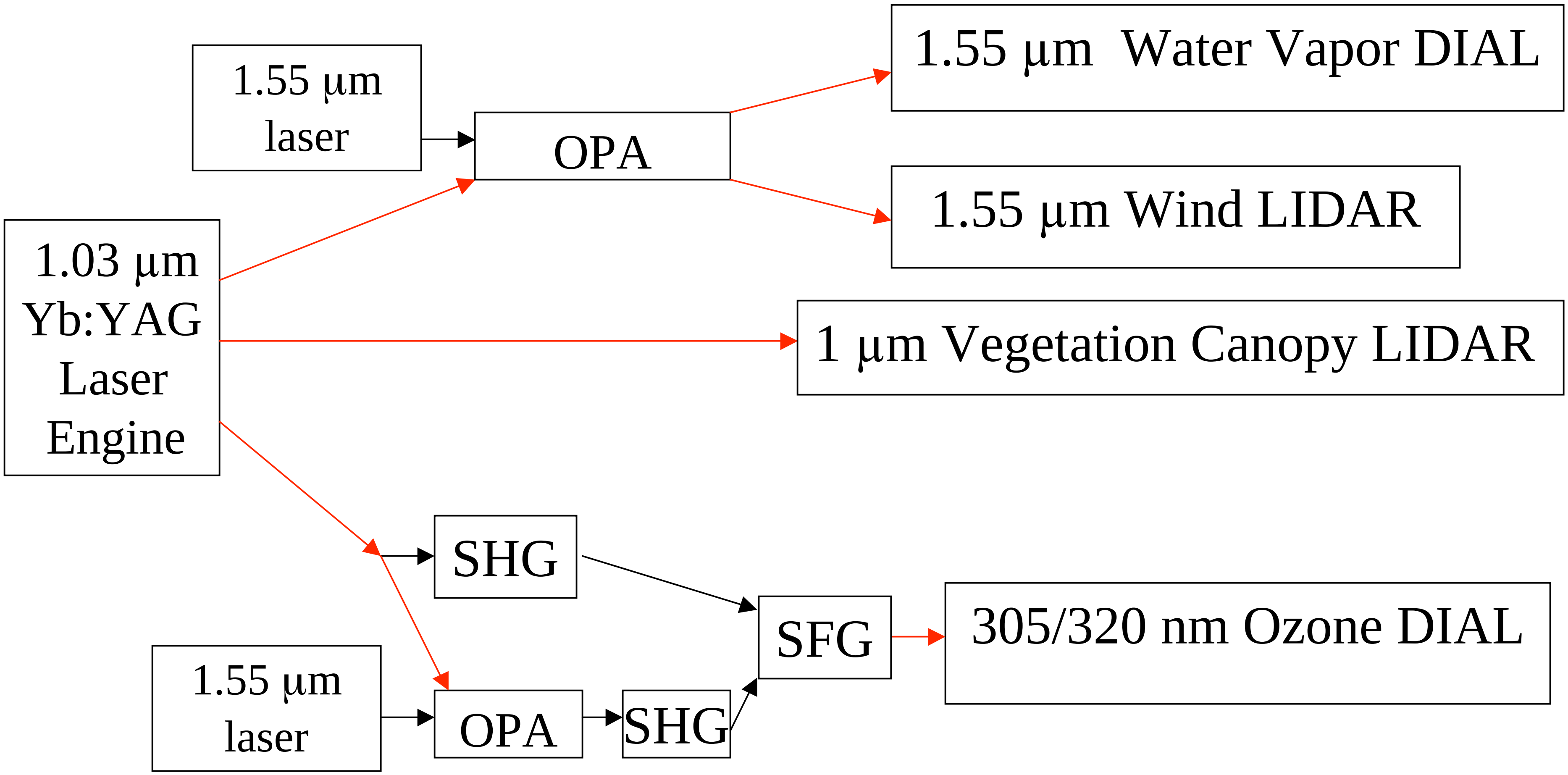
- **Tropospheric Ozone(O_3), NO_2, SO_2 detection**
  - 1-2 km vertical resolution.

<u>Laser transmitter specifications for Ozone detector</u>

- Energy: 0.5 J/pulse
- Repetition rate: 10 Hz
- Pulse width: ~ 1μs
- λ = 305 nm, 320 nm



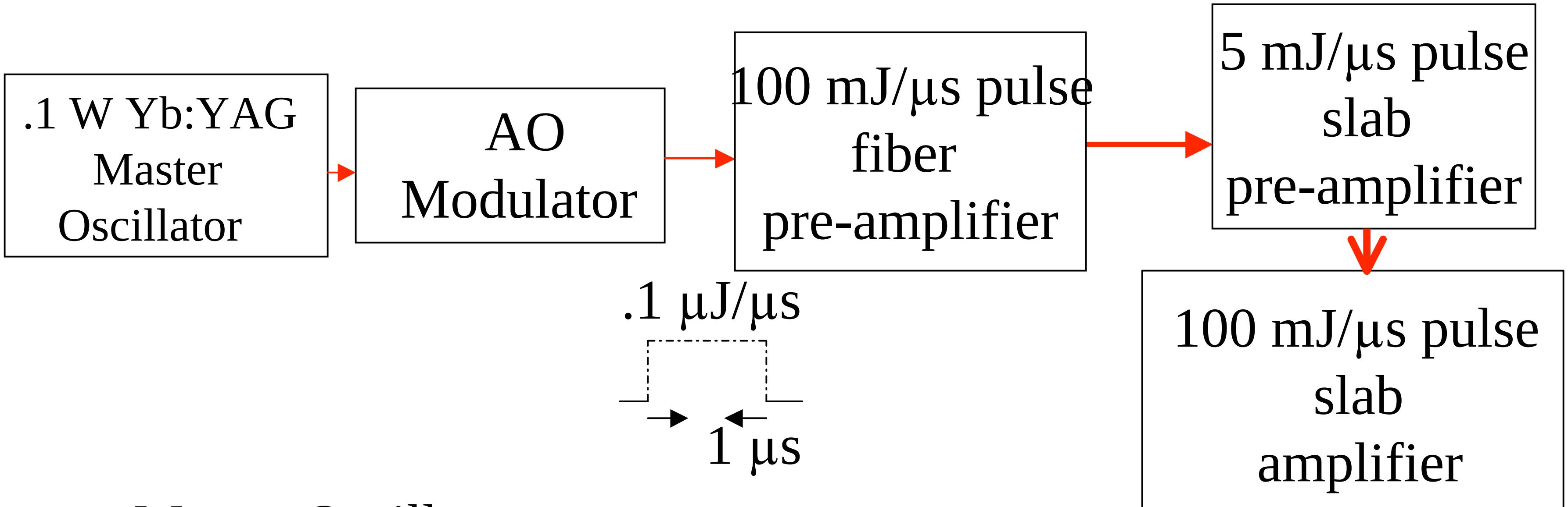
Stanford Approach: Yb:YAG Laser + Non-linear Frequency Conversion

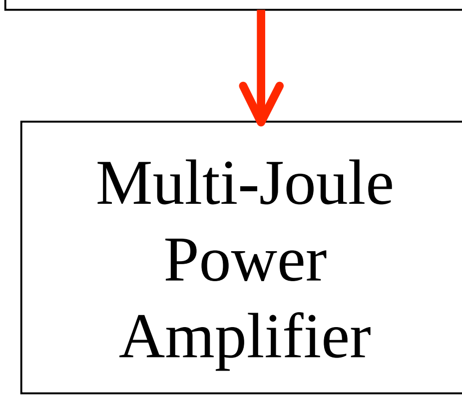


Outline

- Yb:YAG Laser Engine
  - Choice of gain media, pulse format, design and experimental results
- Nonlinear Frequency Conversion Module
  - Nd:YAG MOPA Testbed
  - Waveguide PPLN OPA
  - Bulk PPLN OPA
  - Future directions for pulse energy scaling
- Conclusion

1.03 μm Yb:YAG Laser Engine





Master Oscillator Power Amplifier (MOPA) Advantages

- Scalability
- Good beam quality
- Coherence

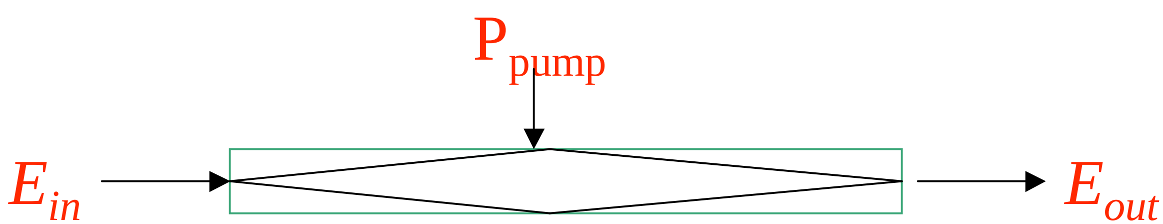
Challenges to Energy Storage/Extraction

P_{pump}

E_{in} → Optical Amplifier → E_{out}

$$E_{out} = E_{in} e^{g_0 l}$$

(small-signal limit)

- $E_{stored} = g_0 l \, F_{sat} \, A$ → High $g_0 l$ is needed for energy storage.
- $F_{sat} < F_{input} < F_{damage}$ → Needed for efficient extraction in power amplifiers
- 

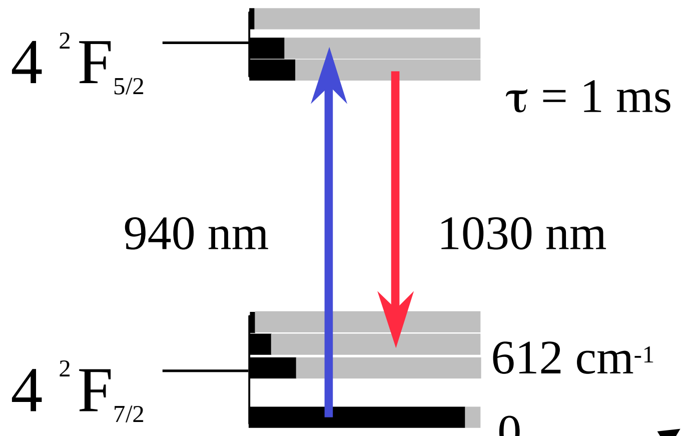
Closed loop parasitic oscillation reduces amplifier gain

Steps need to be taken to prevent loss of stored energy.

Why Yb:YAG ?

$$\frac{\lambda_{p\_940nm}}{\lambda_{l\_1030nm}} < 9\%$$

means high efficiencies are possible.



Yb:YAG

Energy stored $\propto P_{pump}\,\tau$

Long τ means, fewer diodes are required and lower costs

$$g_0 l = \Delta N \sigma_e l < 3$$

Parasitic oscillation limit

→ 10 × smaller σ_e compared to Nd:YAG leads to 10 × higher energy storage

- $E_{stored} = g_0 l\, F_{sat}\, A$

Why 1 μs Pulses?

1. Transform limited 1 MHz line-width, required for 1 m/s global wind velocity resolution.

2. Surface damage fluence (*J*) of YAG and PPLN* scales as $t^{1/2}$

10 J/cm^2

$$J_{damage\_1\mu s} > 10\ J_{damage\_10ns}$$

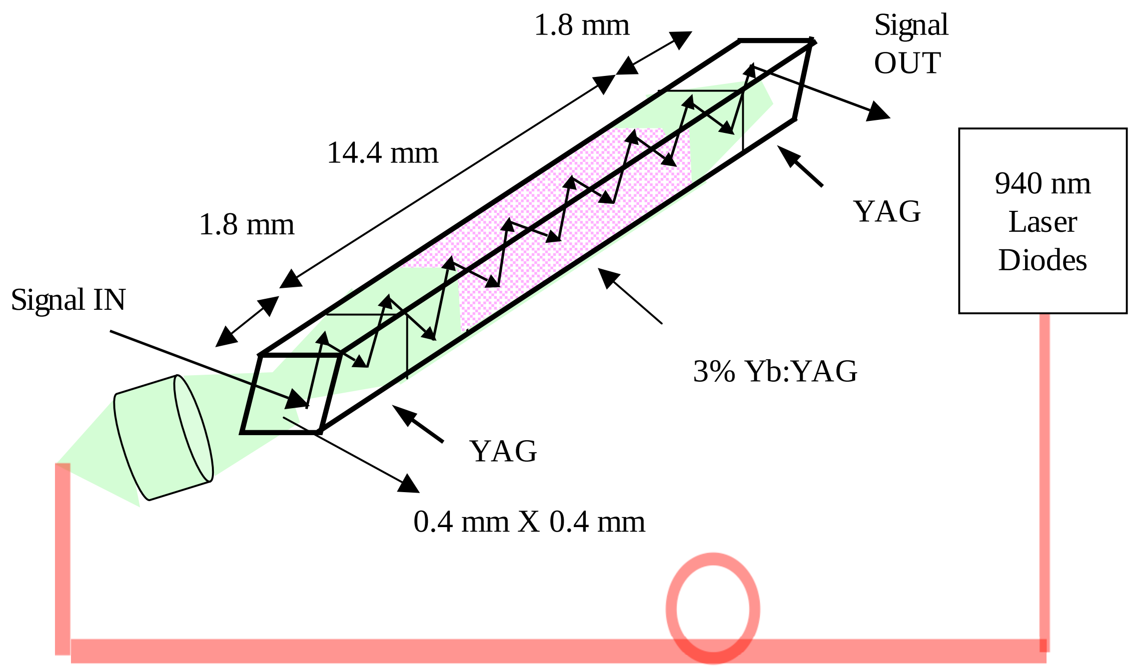
Available from traditional Q-switched lasers

$$F_{sat} < F_{input\_1\ \mu s} < F_{damage\_1\mu s}$$

Enables high-pulsed energy non-linear frequency conversion

*** AR coated PPLN crystals show J_{damage} = 10 - 15 J/cm^2 for 20 ns pulses**

End pumped slab geometry*



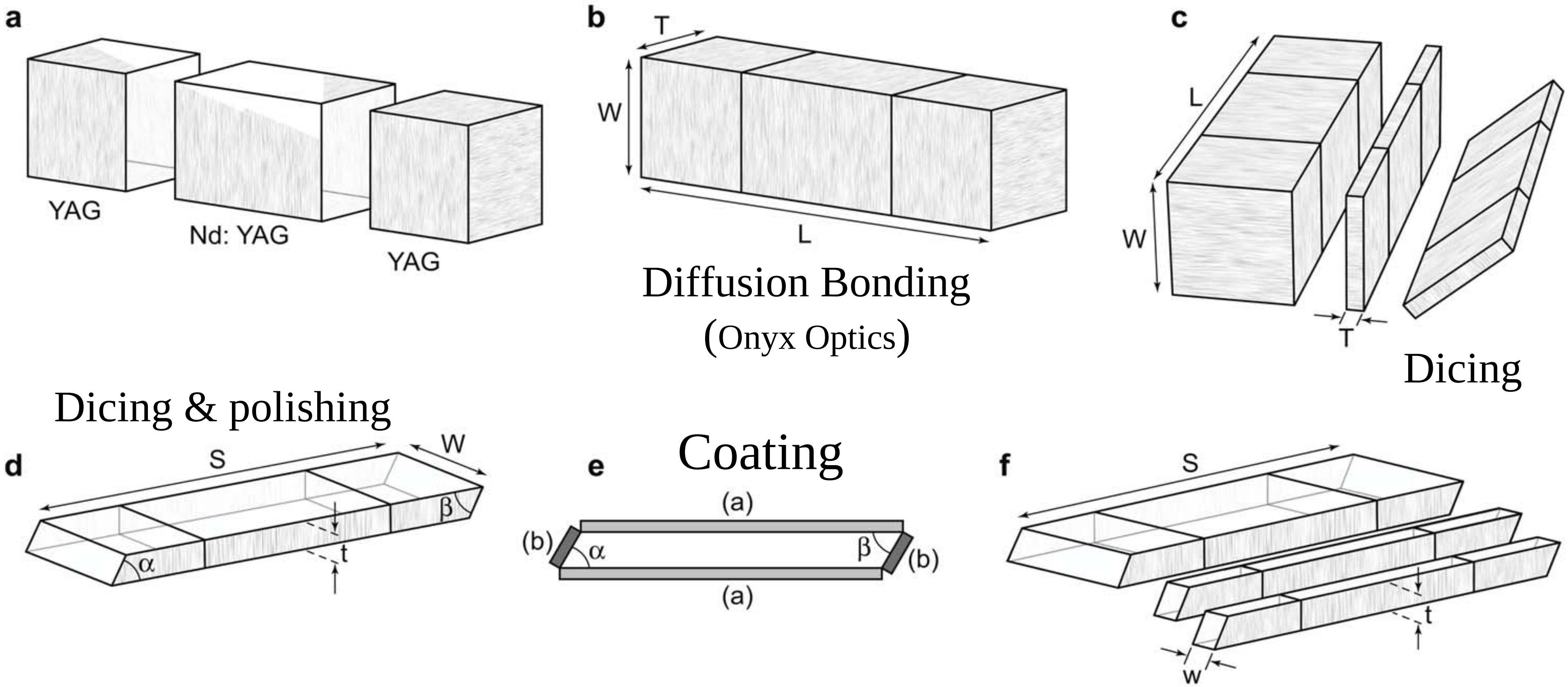
Slab Design Issues

1. Pump light coupling and absorption
2. Minimizing spatial distortion of signal beam
3. ASE & Parasitic Oscillation suppression

Parasitic suppression is accomplished by special cladding on all four large surfaces

- Nearly complete absorption of pump light.
- Better mode overlap => Higher gain & efficiency
- Uniform gain across beam => better mode quality

Slab Batch Fabrication Procedure

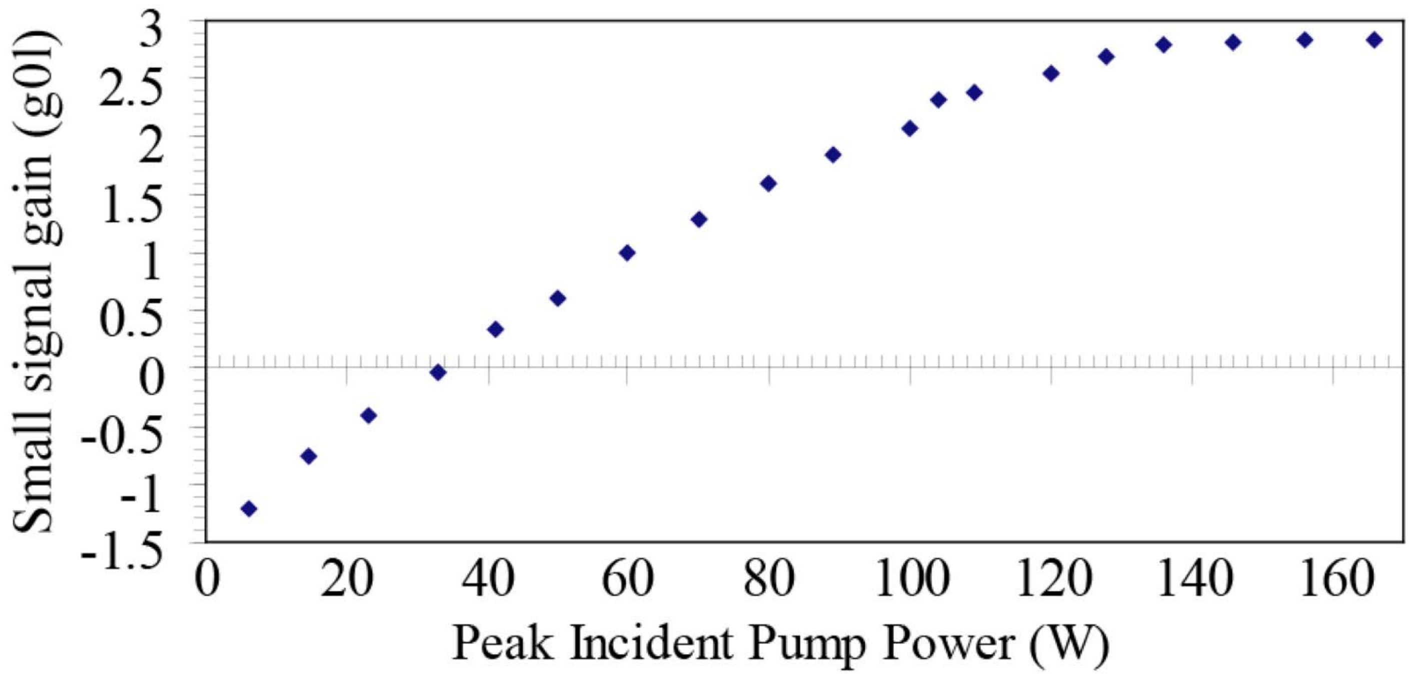


Cost/slab < $ 2000

Should enable wider use of slabs in commercial systems

Yb:YAG slab amplifier gain

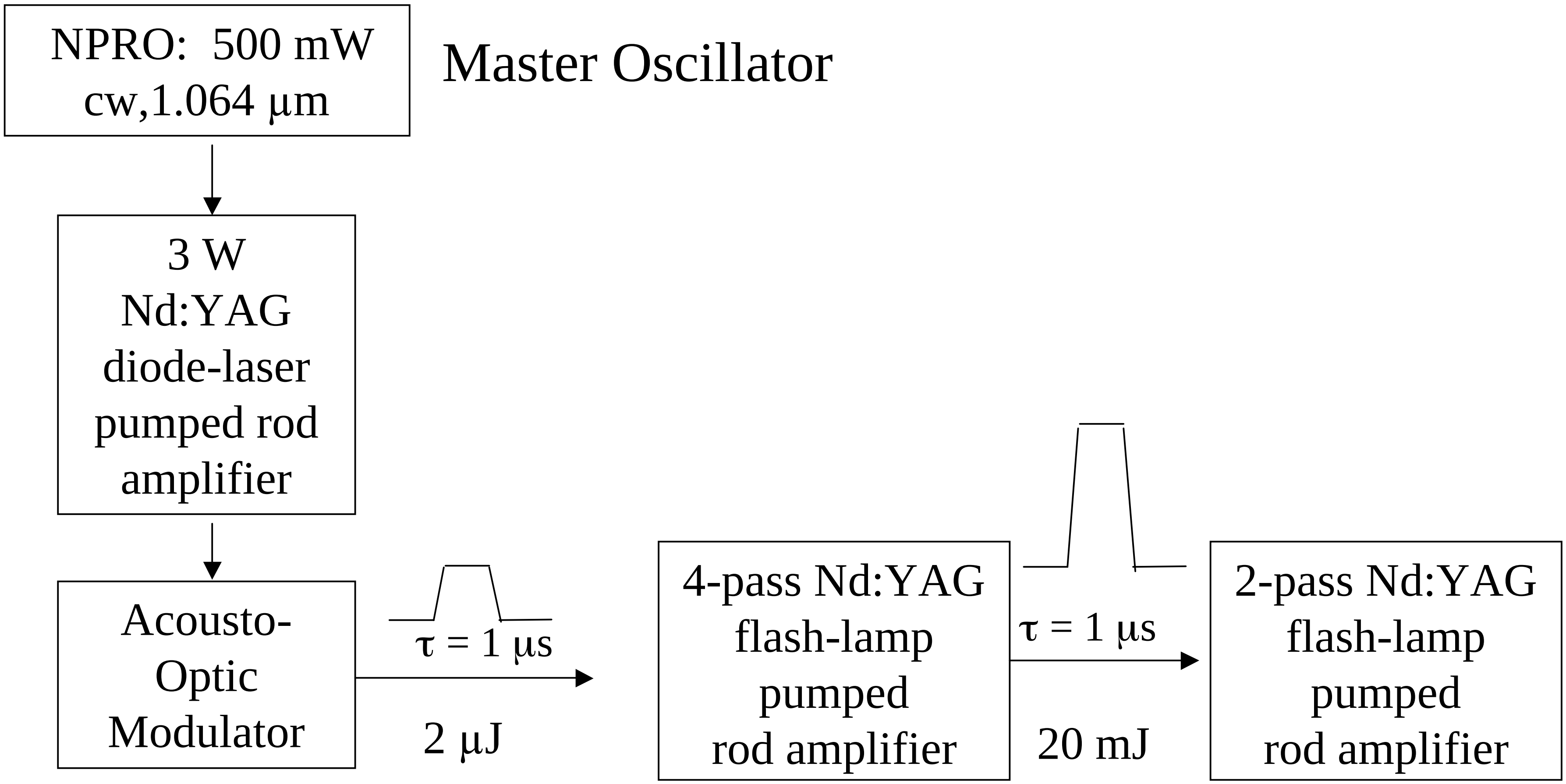
Koheras Fiber Laser 100 mW cw,1.030 μm → Acousto-Optic Modulator → Single-pass, laser-diode end-pumped, Yb:YAG slab pre-amplifier



This key result should enable an efficient high pulse energy Yb:YAG MOPA

Nd:YAG MOPA Test-bed

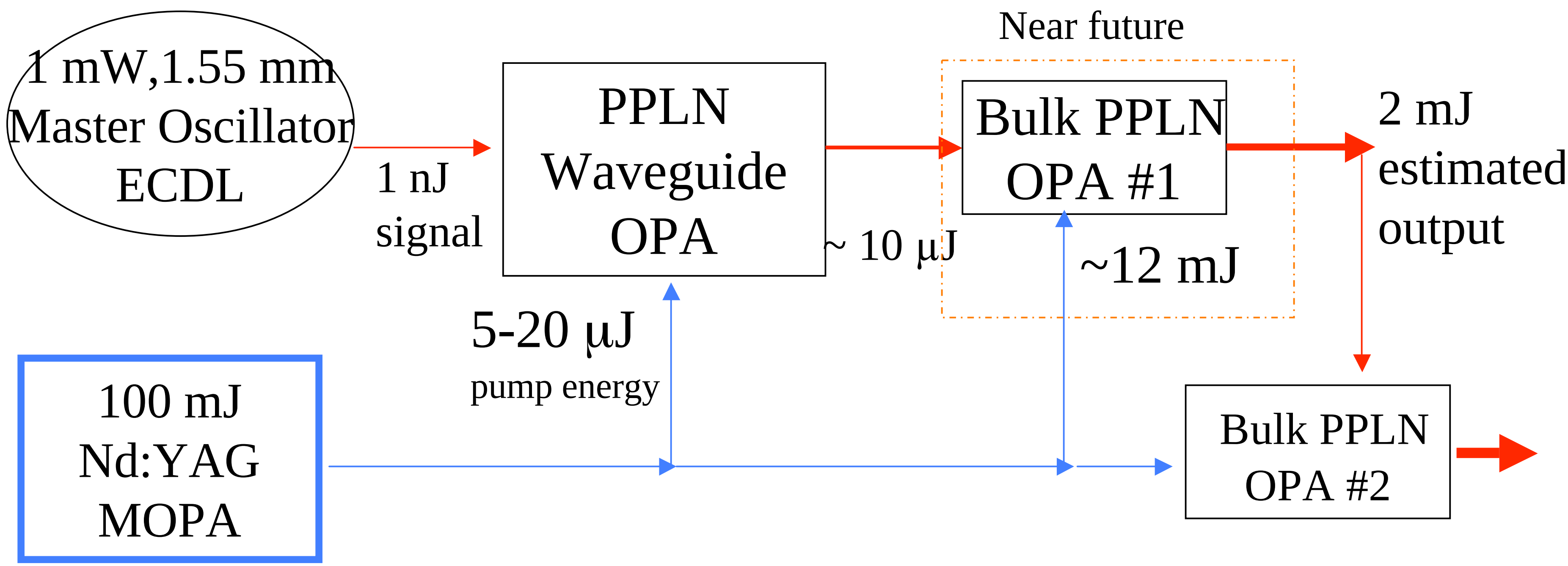
for Nonlinear Frequency Conversion: Experimental Setup



AOM can generate pulses with $\tau \geq 200$ ns

Output: >100 mJ, 1 μs pulses @ 1.064 μm

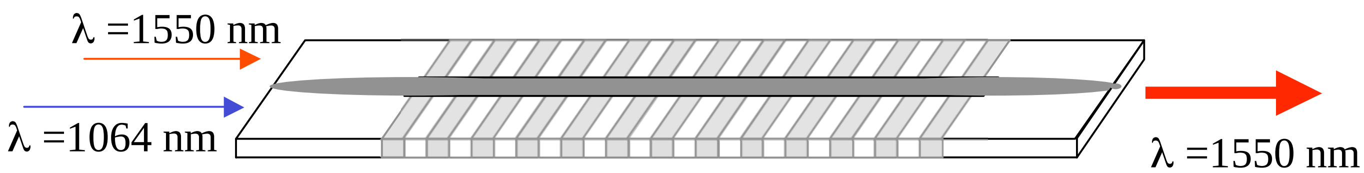
PPLN based Optical Parametric Amplifier (OPA) System Schematic

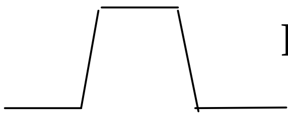


Conversion efficiency in waveguides 2-3 orders of magnitude higher than in bulk mixing

High gains in waveguide pre-amplifier offers potential for easier depletion of pump energy in bulk OPAs, and minimizes # of components.

Waveguide OPA:Results





Peak incident pump energy ~ 5 mJ

Signal energy = 0.7 nJ

Experimental result: 45 dB gain

Propagation loss at 1.55 μm- ~0.14 dB/cm

MF length=1.2mm, MF width=2.5 μm

Quadratic taper length=4.5mm

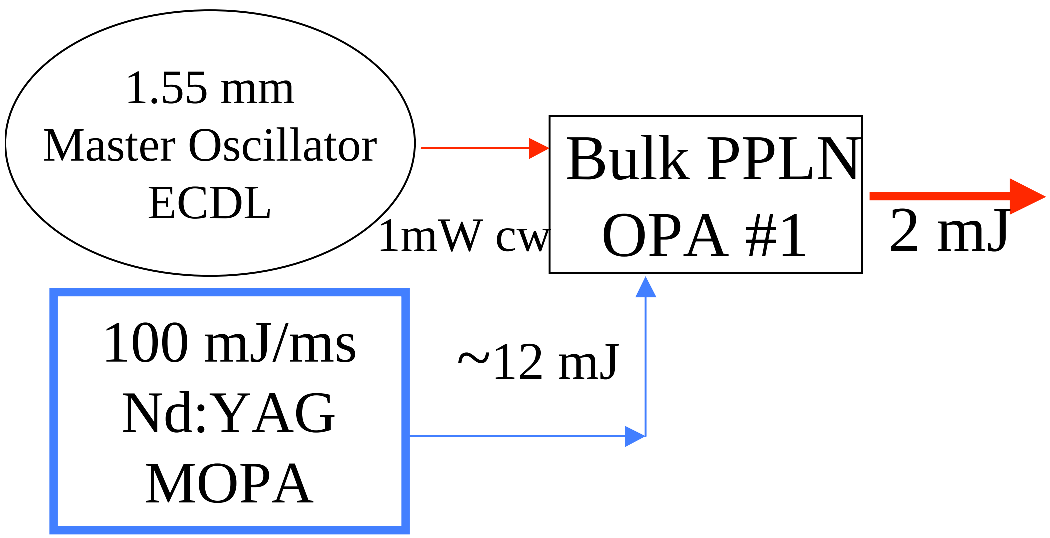
QPM length=56 mm

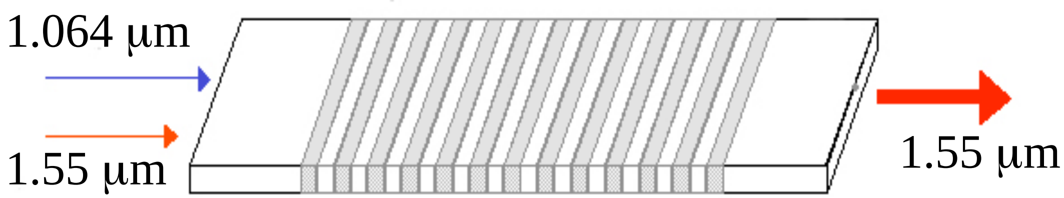
normalized efficiency ~10 %/Wcm^2

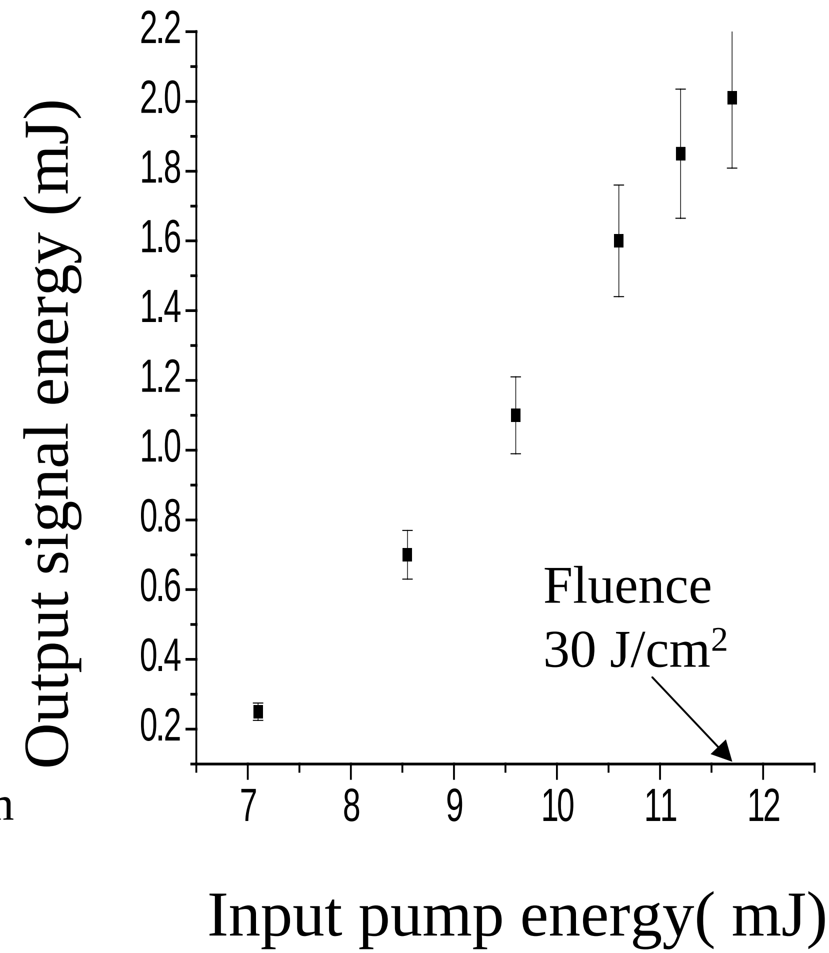
Theoretical expectation: 14%/Wcm^2

Tuning curve FWHM ~ 1 nm

Bulk PPLN OPA







L = 29.9 µm, l = 8.4 cm, t = 0.7 mm

w_{p_x} = 180 µm, w_{p_y} = 140 µm, w_s = 130 µm

Future potential scaling of OPA

Stoichiometric PPLN

Low coercive electic field

3-4 mm thick crystals

Increased pump spot size prevents surface damage

Low defect concentration

Photorefractive damage threshold increased

Room temperature operation possible

Negligible Green-Induced IR Absorption

Target→ 2 J, 1.55 mm, μs pulses possible with 5 J pump energy

Conclusion

Key Laser Engine Achievements

- Demonstrated record 12 dB ($g_0 l = 2.84$) gain in end-pumped zig-zag slab amplifier.

- Scaling of aperture size and available pump power should enable efficient scaling of Yb:YAG MOPA to Joule energy levels

Non-linear frequency conversion module developments

- 100 mJ/ms Nd:YAG Testbed MOPA enabled
  - Testing of PPLN RPE waveguide OPA's with 45 dB gain.

  - Testing of first Bulk PPLN OPA with 2 mJ pulses at 1.55 mm

- Pulse energy scaling of OPA's by increasing aperture size (PPSLT,PPSLN ?)
 will be key to meeting end remote sensing requirements.